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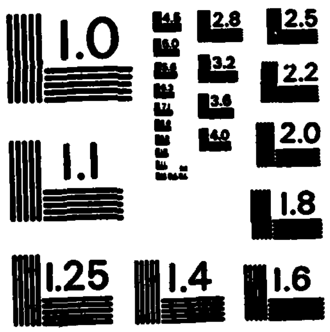

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The International Geophysical Year (IGY) programs have special significance to geodesists. The IGY witnessed the launching of the first manmade earth satellite and the beginning of the era of global geodesy. It is no wonder that the U.S. Department of Defense (DoD) with its global requirements developed an early interest in satellite geodesy. Specifically, this led to the use of early satellites of opportunity (and subsequently of dedicated satellites) for worldwide navigation, geodetic positioning and gravimetric

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On this occasion marking the 25th Anniversary of the IGY, this paper recalls some of the DoD activities of the initial years which fulfilled the geodetic objectives of the IGY and highlights those activities which grew out of the IGY to become today's technology.

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OF

THE DEPARTMENT OF DEFENSE

UNDER

THE INTERNATIONAL GEOPHYSICAL YEAR PROGRAMS

by

Owen W. Williams

and

Kenneth I. Daugherty

Paper to be presented

at the Fall Meeting

of the American Geophysical Union,

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ABSTRACT

The International Geophysical Year (IGY) programs have special significance to geodesists. The IGY witnessed the launching of the first manmade earth satellite and the beginning of the era of global geodesy. It is no wonder that the U.S. Department of Defense (DoD) with its global geodesy requirements developed an early interest in satellite geodesy. Specifically, this led to the use of early satellites of opportunity (and subsequently of dedicated satellites) for worldwide navigation, geodetic positioning and gravimetric investigations. In conjunction with other civilian satellite programs under the IGY, DoD played a major role in the achievement of geodetic goals perhaps far beyond that which was envisioned originally.

An early satellite program was the Project ANNA with the basic concept originating from the DoD. ANNA, a truly cooperative effort, involved the three defense services, NASA and other civilian agencies. Other examples under satellite programs included many camera and electronic measuring techniques, especially the U.S. Navy's Doppler System, the Army's SECOR and the pioneering development of laser illuminating and ranging experiments by the Air Force.

On this occasion marking the 25th Anniversary of the IGY, this paper recalls some of the DoD activities of the initial years which fulfilled the geodetic objectives of the IGY and highlights those activities which grew out of the IGY to become today's technology.

1. INTRODUCTION

Any discussion of the U.S. Department of Defense participation in the International Geophysical Year (IGY) must begin by recalling the state of geodesy in 1957. Geodetic observations were generally limited to "line of sight" between two mountain tops. Coordinates of places, say in North America, were known relative to those in Eurasia to an accuracy of perhaps a couple hundred meters or so. The earth ellipsoid derived by Hayford in 1910 had been named the "International" in Madrid in 1924, and had been used to adjust the European Datum in 1950. Recall that the value of the semi-major axis was said to have a standard error of 18 m. Today we know that Hayford's value was too large by about 250 m, and the standard error of the GRS 80 semi-major axis is 2 m.

The Potsdam determination of absolute gravity and the International gravity formula represented the "state-of-the-art" in gravimetry.

In the matter of education, prior to 1955, there were no Ph. D granting programs in geodesy in the entire Western Hemisphere.

So, it is not surprising that the U.S. Department of Defense, with its global requirements for geodetic and geophysical information assumed a leading role in the programs of the IGY. During the ensuing 25 years DoD has dramatically demonstrated its serious commitment to the enhancement of geodetic and geophysical knowledge on an international scale. There is little doubt that the present-day state-of-the-art in geodetic science owes its existence in a large part to the efforts of the U.S. DoD. The long list of technological developments which received their impetus and funding from DoD includes such items as rocket flare triangulation (when we were attempting, in the early days, to tie distant land masses together), the application of lunar occultations for geodesy, airborne gravimetry, the use of satellites for surveying, the application of inertial technology to surveying and many others.

The International Geophysical Year (IGY) programs, a truly remarkable scientific enterprise and a cooperative effort shared by over 50 nations, formally began on 1 July 1957. However, some earlier operations such as the landing of U.S. Naval and Air Force aircraft in McMurdo Sound and the opening of the Amundsen-Scott South Pole Station during October 1956 well in advance of the full-scale IGY were clear indications of the faith, interest and commitment the U.S. Department of Defense (DoD) in general had in the IGY.

The launching of the first manmade earth satellite announced the explosive arrival of the "real" space age in geodesy and DoD developed an early interest in the resulting infant science of satellite geodesy. Specifically this led to the use of early satellites of opportunity (and subsequently of dedicated satellites such as PAGEOS, GEOS and the Navy Navigation Satellite System) for worldwide navigation, geodetic positioning and gravimetric investigations. The activities also resulted in the establishment of DoD's pioneering World Geodetic System (WGS) 1960 defining a global geodetic network, geoid and the earth's gravity field model.

In conjunction with other civilian satellite programs under the IGY, DoD played a major role in the achievement of geodetic goals, perhaps far beyond that which was envisioned originally. An early start was the project ANNA.

Other earlier satellite programs from DoD also included many camera and electronic measuring techniques, especially the U.S. Navy's Minitrack and Doppler system (or the Navy Navigation Satellite System, NNSS), the Army's SECOR (or Sequential Collation of Ranges) and the Air Force's PC-1000. From a conservative objective of a 200 m navigational accuracy the Doppler system today has become an extremely practical geodetic tool which routinely provides geodetic network control of 1 m or better accuracy over entire continents. And now, the Air Force's latest 18 satellite Global Positioning System (GPS) promises worldwide geodetic accuracies of subdecimeter level.

As part of the overall objective of the IGY gravity program, DoD has always played a major role in the extension and completion of a worldwide network of gravity measurements. From the initial measurement of pendulum bases for control purposes, the DoD effort has been to conduct research and develop better instruments, to provide financial help to other civilian agencies and universities for such activities and to aid materially in eliminating the serious gaps in the international network of gravity measurements.

2. IGY ACTIVITIES

More than five years of extensive planning and preparation were devoted to the development of the 1957 IGY programs which were to become a concentration of intense effort to diminish great gaps in our knowledge of the planet earth and its surrounding regions. It should be remembered that the synoptic objectives of these programs also included simultaneous observations in most of the disciplines including polar, weather, solar and ionospheric programs, throughout the world. To achieve simultaneous observations, regular schedules were arranged through international cooperation. To achieve the desired intensification in the observational programs, Regular World Days (RWD) and Special World Intervals (SWI) programs were also designated. The driving motivation was that the resulting concentration of efforts under these programs would be useful in the interpretation of overall results.

If DoD was not in the forefront in every program, it was there contributing one way or the other. Having had direct or indirect experience in all of these activities, we want to share here with you the role which DoD played in the IGY programs.

3. SATELLITE PROGRAMS

The geodetic satellite programs and satellite geodesy grew out of the upper-air rocket research activities, both during IGY and previous years. The Air Force Cambridge Research Center, now the Air Force Geophysical Laboratory (AFGL), Army Ordnance, Naval Research Laboratory (NRL), Navy Bureau of Ordnance, Holloman Air Force Base, Naval Air Missile Test Center and various U.S. Navy ships, e.g., "The Compass Island", are some of the DoD components which were always in the forefront. Research rockets provided extremely valuable information regarding pressure, temperature, density, and chemical and ionic composition of the atmosphere. They also yielded information about winds, airglow, ionospheric charge density and refraction, solar radiation and the earth's magnetic field, in addition to being the forerunners of the satellite flights.

What a coincidence it turned out to be! The IGY also witnessed the launching of the first manmade earth satellite and the beginning of the era of global geodesy. The use of satellites as additional tools in geodetic research and operations was immediately adopted universally, with the official endorsement for such a role coming from the International Union of Geodesy and Geophysics (IUGG) in 1960.

Our interest within DoD started with the use of early satellites of opportunity and then quickly turned into programs for the development of dedicated geodetic satellites. Some of the early satellite programs and the associated geodetic goals under the IGY are worth highlighting here since the experience gained from them became the foundation for further development.

(A) Project ANNA

With the basic concept originating from DoD in 1958, ANNA was a truly cooperative effort and soon became the test bed for satellite geodetic methods. The extensive research and dedicated efforts of the three defense services, NASA, the Applied Physics Laboratory (APL) and other civilian agencies resulted in the launching of ANNA 1A on 10 May 1962. However, the attempt to place the first "true" geodetic satellite into orbit failed when the second-stage rocket engine did not ignite. Thus ANNA 1B, launched on 31 October 1962, has the distinction of being the first geodetic satellite.

The basic mission for ANNA 1B was to improve existing geodetic control and to test and compare the performance of other forthcoming systems such as a transponder from the Army's SECOR, flashing lights for the Air Force's PC-1000 camera, NASA's MOTS camera and NGS's (then U.S. Coast and Geodetic Survey) BC-4 camera and a Doppler beacon for the APL and NWL's tracking systems.

(B) The Minitrack Systems

Prior to the launching of U.S. satellites under the IGY programs, NRL had already established Minitrack stations. The first satellite, Explorer-1 launched in 1958, was a joint venture between the Army Ballistic Missile Agency (BMA) and the Jet Propulsion Laboratory (JPL). The second satellite, Vanguard 1, was sponsored by NRL and the third was again a joint effort of BMA and JPL. These two satellites followed within the next two months of the Explorer-1.

Even in those early years, the Vanguard satellites were associated with an orbital lifetime of at least 200 years. It was also expected that these satellites with their spherical shape and stable orbits would prove very useful in geodetic and air density studies. Of course, not all those expectations became realities, but the Vanguard IGY satellite program definitely succeeded in laying down a sound foundation for the other projects to follow.

Visual observations were not expected, but the Moonwatch teams of Holloman AFB were the first to report the visual sightings of 1958 α and 1958 β satellites. NRL's tracking system became so dense during the early years of this program that it created an electronic "fence" along the 75th west meridian which every satellite had to cross.

Under the Vanguard 1 satellite program, the comparatively inexpensive Minitrack Mark II (developed from Mark I) ultimately became operational and was later routinely used by NRL for tracking and obtaining useful data for orbit computations. However, the Minitrack system did not remain in use for long; it was replaced by more promising systems.

(C) PC-1000 Geodetic Camera System

The development for this camera system began near the end of IGY activities at AFCRL. This Air Force program consisted of an eight-element lens of a focal length of about 1000 mm, and hence the name. Its chopping shutter allowed observations of the flashing lights from ANNA 1B (Section 3(A)) or subsequent geodetic active satellites like GEOS 1. This shutter performed equally well with the passive satellites such as ECHO or PAGEOS which followed later.

These cameras were utilized for long range space triangulation for global/continental geodetic control networks. One such network, extending from Curacao to Asuncion, which can be commendably mentioned here, provided much needed control over South America.

(D) Navy Navigation Satellite System

The concept for the Navy Navigation Satellite System (NNSS) or the Doppler system became a reality in 1958. By 1959 the experimental satellite TRANSIT 1A and five tracking stations had been designed and constructed.

Although the TRANSIT 1A satellite failed to achieve orbit, a full development program for the system officially began in 1959. The program's success started with the next satellite TRANSIT 1B (launch date of 13 April 1960) and continued with followups like TRANSIT 2A, 3B, 4A, 4B, 5A, etc.

The Doppler system witnessed another threshold with the generation of new drag free satellites, the first of which was NOVA 1 (launch date of July 1981). The accuracy improvement has been phenomenal from the modest goals of about 200 m of the earlier years. The Doppler system of today has become one of the most efficient, accurate and practical geodetic tools for routinely providing geodetic control of 1 m accuracy, both for individual stations and/or as part of a station network.

(E) Geodetic SECOR System

The concept for this system also originated near the end of the IGY years and the first transponder went into space with ANNA 1B (Section 3(A)). The system was based on the solution of a ground based four station tracking pyramid with the satellite transponder as the vertex in space. Over the duration of the SECOR system, an equatorial belt of tracking stations was established. Many of the stations were colocated with BC-4-stations, thus providing additional scale to the PAGEOS network.

After the first SECOR transponder was carried in ANNA 1B, the Army launched additional high and low altitude satellites for the SECOR system between 1964 and 1970. The system was then phased out due to the high cost associated with the operational methods. Some of the research regarding the critical configuration for a geometric solution and concerning the successful application of the SECOR in its simultaneous mode only became available after 1970. Later results from the system which compensated for the critical configuration were very promising. SECOR station position recovery with an rms error of 2.5 m compared very favorably with the 4-5 m of the BC-4, PC-1000 and Baker-Nunn systems. It seems that the SECOR may have become operational ahead of its time.

(F) Other Systems

The first Baker-Nunn camera of the Smithsonian Astrophysical Observatory was installed at Organ Pass, New Mexico, on 15 November 1957. Shortly thereafter the U.S.-IGY program established 12 worldwide tracking stations. In this extensive optical tracking program, DoD was there to provide valuable logistic and operational support.

The 1959 Iota satellite was placed in orbit by the Army Ballistic Missile Agency as a contribution to the 1959 extension of the IGY, the International Geophysical Cooperation 1959. It turned out to be the last satellite of the IGY programs. The vital initial tracking of 1959 Iota was accomplished by U.S. Army Microlock stations in the U.S.A. and Bermuda.

Another satellite program worth mentioning was NRL's Solar Radiation Measuring Satellite or "Sunray". This satellite was carried in a "piggyback" mode with the TRANSIT IIA vehicle of the Doppler System. Although the project was of primary interest to geophysicists, the ionospheric research also contributed information of value for geodesists about accurate orbit computations.

4. SATELLITE GEODESY

If the concepts and the groundwork for the era of satellite geodesy had been laid before the IGY years through research rockets, the results of geodetic importance came after the launching of the first manmade earth satellite. It was the team of DoD scientists headed by John O'Keefe in 1958 which determined the first definitive result of 1/298.3 for the earth's flattening using the Vanguard satellite.

From the investigations regarding variations in the orbit of Vanguard 1, DoD was again in the forefront to suggest a modification to the traditional concept of the earth as a rotational ellipsoid. The calculations established the existence of a third zonal harmonic which in turn required a tri-axial ellipsoid with an elliptic geodetic equator and the earth's shape somewhat resembling a pear.

Through its activities and commitment to the satellite program during the IGY (Section 3) and the following years, DoD continued to take a very keen interest in satellite geodesy. It is no surprise that in 1957 two of the three agencies working on global geodetic positioning were from DoD.

Even if the geodetic activities under the IGY did not provide all the solutions, the research originating under IGY programs became the foundation of achievements which followed in later years. A striking example here would be the NNSS or the Doppler effort. It would be impossible, in the allocated time and space, to adequately describe the achievements in this area. Once the navigational requirements were satisfied, TRANET observations of the Doppler shift were utilized over the years for continuous improvement of our knowledge of the geocentric coordinates of earth-fixed points, establishment of ties between world datums and determination of polar motion and the earth's gravitational model.

The launching of the first satellite during the IGY and the subsequent launching of dedicated geodetic satellites started a new era of global "datums". DoD was first to solve such a datum in 1960. The solution which became known as the World Geodetic System (WGS) 1960 thus provided for the first time a "truly" geocentric worldwide coordinate system for global mapping and charting.

5. GRAVIMETRIC INVESTIGATIONS

Under the IGY gravity program, DoD played two important roles: first to actively participate in gravity measurements all over the globe and second, to provide logistic support to other agencies in remote areas like the Arctic and Antarctic.

The measurement program, besides filling in the gaps where gravity observations were scarce and of doubtful accuracy, included the establishment of first-order stations, the calibration of gravimeters, the verification of the connections between established stations and the extension of the world-wide gravity net including ocean areas. In remote territories like Antarctica, gravity measurements were also made in conjunction with seismic and glacial studies to improve our knowledge of isostatic compensation in that area.

DoD was also one of the pioneers which recognized the importance of a "combined" solution from surface gravity information and observations of satellite orbit perturbations available from the IGY earth satellite programs. From the initial computation of the third zonal harmonics in early 1959, DoD was among the first to solve a global geopotential model under the World Geodetic System project the following year.

In its logistics support role, the U.S. Navy's ship "The Compass Island" provided a gyro-stabilized platform for the first successful sea surface gravity observations on 29 November 1957. This historic operation thus established that it would be possible to acquire data from over 80 percent of the earth's surface in the succeeding years. Along similar lines, indispensable airborne and ground support were supplied to the IGY Antarctica gravity traverse teams by a U.S. Navy task force.

6. GEODETIC LASER SYSTEM

The pioneering efforts to develop laser illuminating and ranging techniques were conducted by AFGL. The initial experiment with corner-cube reflectors (CCR) by the Army Map Service (now DMA) began in the years following the IGY. These are examples of DoD's indirect contribution to geodesy. It is interesting to note that earlier attempts with CCR's were performed with 60-inch searchlight beams. Based on knowledge acquired as a result of the IGY, it is not a surprise that these attempts failed due to large amounts of backscatter.

As the system design progressed, the CCR's were replaced by more efficient retroreflectors. The original concept to measure distances with geodetic accuracy became a reality. We all know that in today's world lasers form the essential ingredient of some of the most accurate and complex geodetic instruments, and the word laser itself has become synonymous with high accuracy geodesy.

7. SUMMARY

On this occasion marking the 25th Anniversary of the IGY, our paper has recalled some of the DoD activities of the initial years which significantly contributed to the IGY satellite programs involving active, passive and cooperative satellites.

Today, DoD continues to support the development, enhancement and application of new technology in such areas as airborne gravimetry, gravity gradiometry, inertial surveying, interferometry, geodetic lasers, charge coupled devices for geodetic astronomy and others. And, of course, there is a tremendous effort going into the Global Positioning System which is scheduled to be operational later in this decade.

Time does not allow mention of all the contributions made by DoD components which fulfilled the IGY objectives in satellite geodesy theory, practical methodology of data reduction, satellite tracking techniques and instrumentation, gravimetric investigations and other basic research. It suffices to say that much of today's technology is a result of the stimulus provided by the dedicated and concentrated efforts begun during the IGY.

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